What we can learn from the Cosmos

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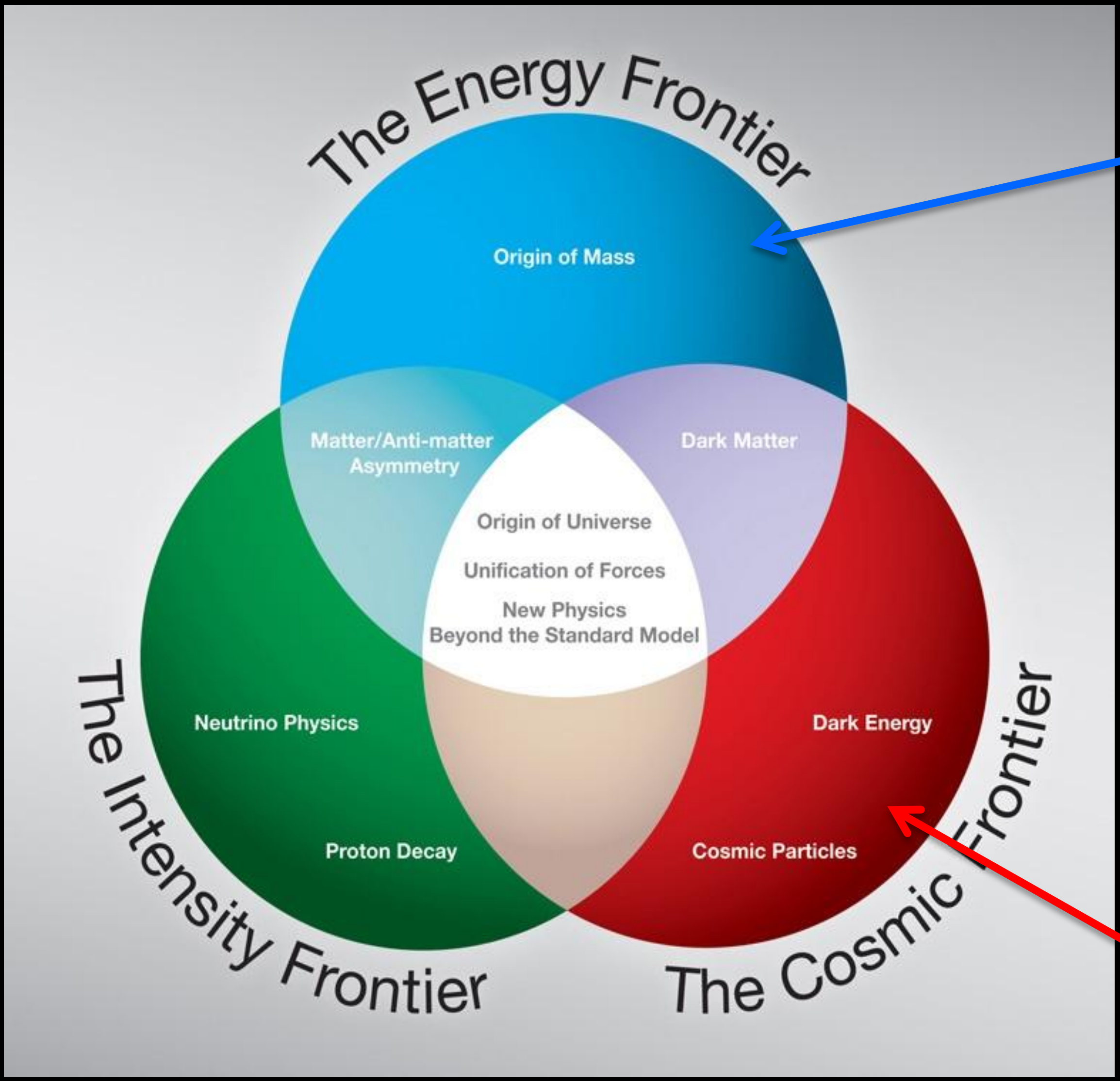
Fermilab

Fermilab Program



I started at Fermilab in 1986 on CDF, studying the smallest things: quarks

2003: the Dark Energy Survey project started.

Now I study the largest things: clusters of galaxies!

What are Dark Matter and Dark Energy?

Why do we believe they exist?

How do we (at Fermilab) look for them?

Why are we interested?

What is Dark Matter?

Dark Matter: some sort of invisible material that feels gravity

But what sort of matter could this be?

Conventional matter doesn't fill the bill (atoms, light, …)

Everything we know about interacts by either emitting or absorbing light

Must be some sort of new matter: Many theories for new dark matter particles, but as yet, no dark matter particle has been discovered

Why do we believe Dark Matter Exists?

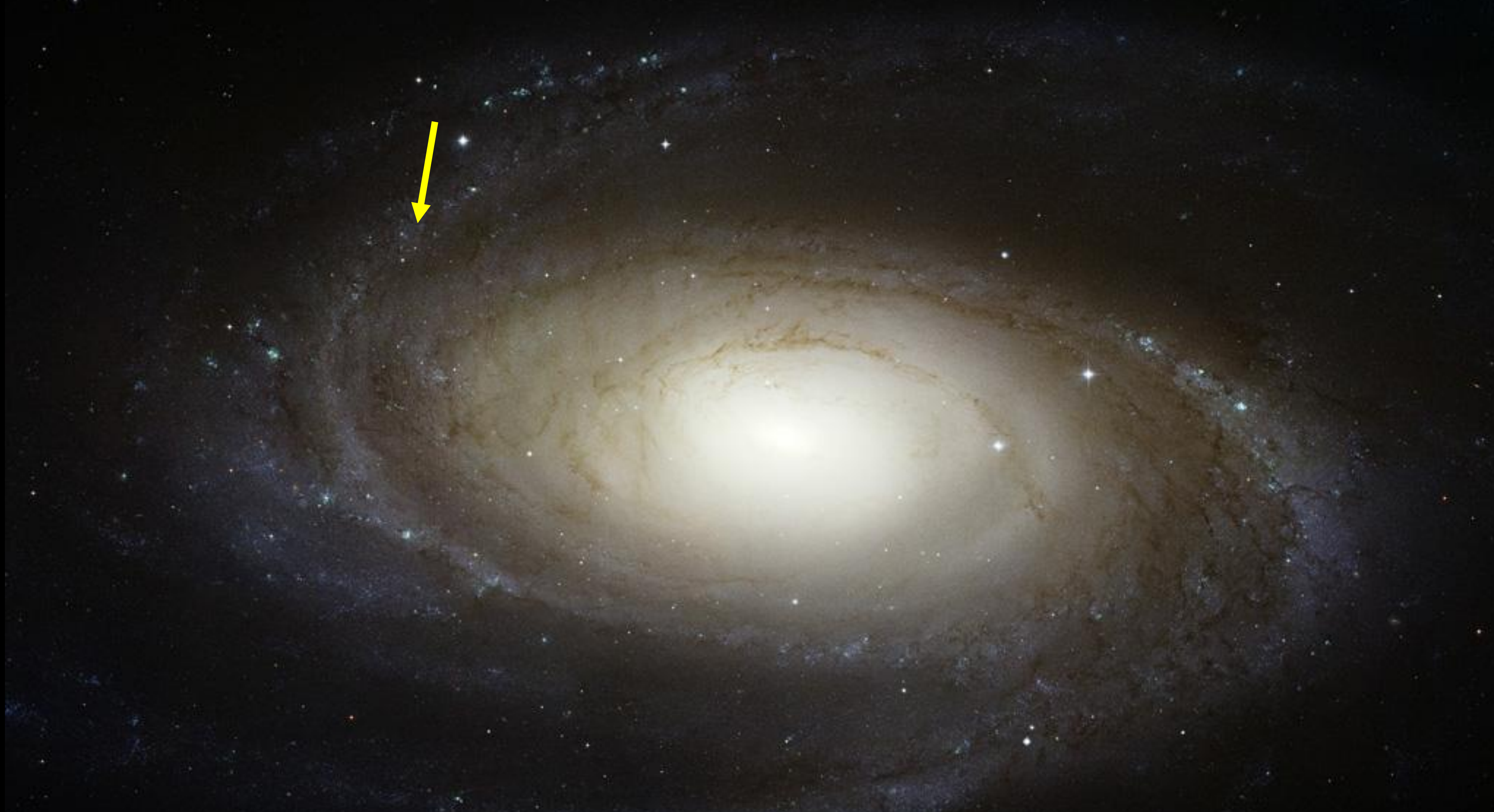
Astronomical observations show that something is providing Gravity, but not emitting light

1) Galaxies rotate too fast

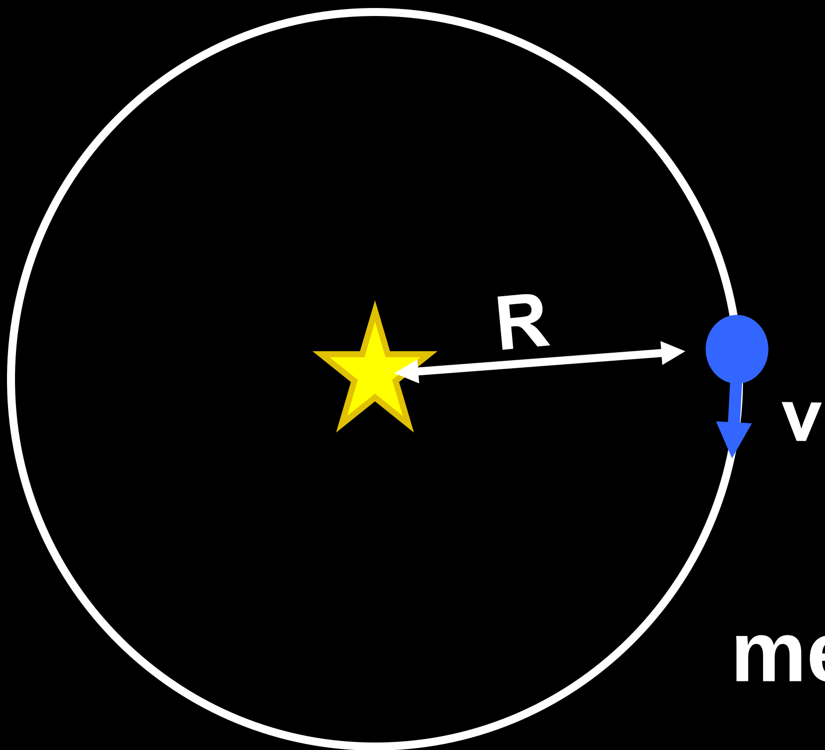
2) Galaxy clusters act as large lenses and distort the images of the universe behind them

Our galaxy, the Milky Way, is a spiral galaxy similar to this one, 12 Million light years away. Arrow shows where our sun would be if this were the Milky Way

(picture taken with HST)

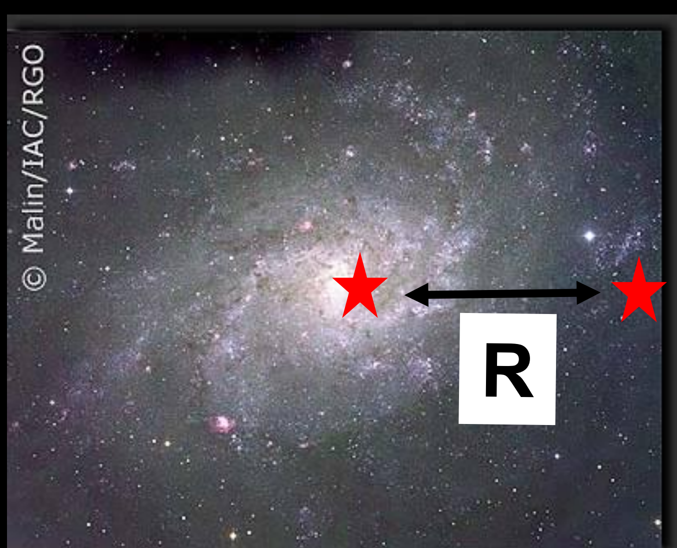


Our solar system is 30,000 light years from the galactic center, and is moving at 450,000 mph.   This is much faster than it would rotate if all the mass was in the stuff we can see (stars, dust, etc)



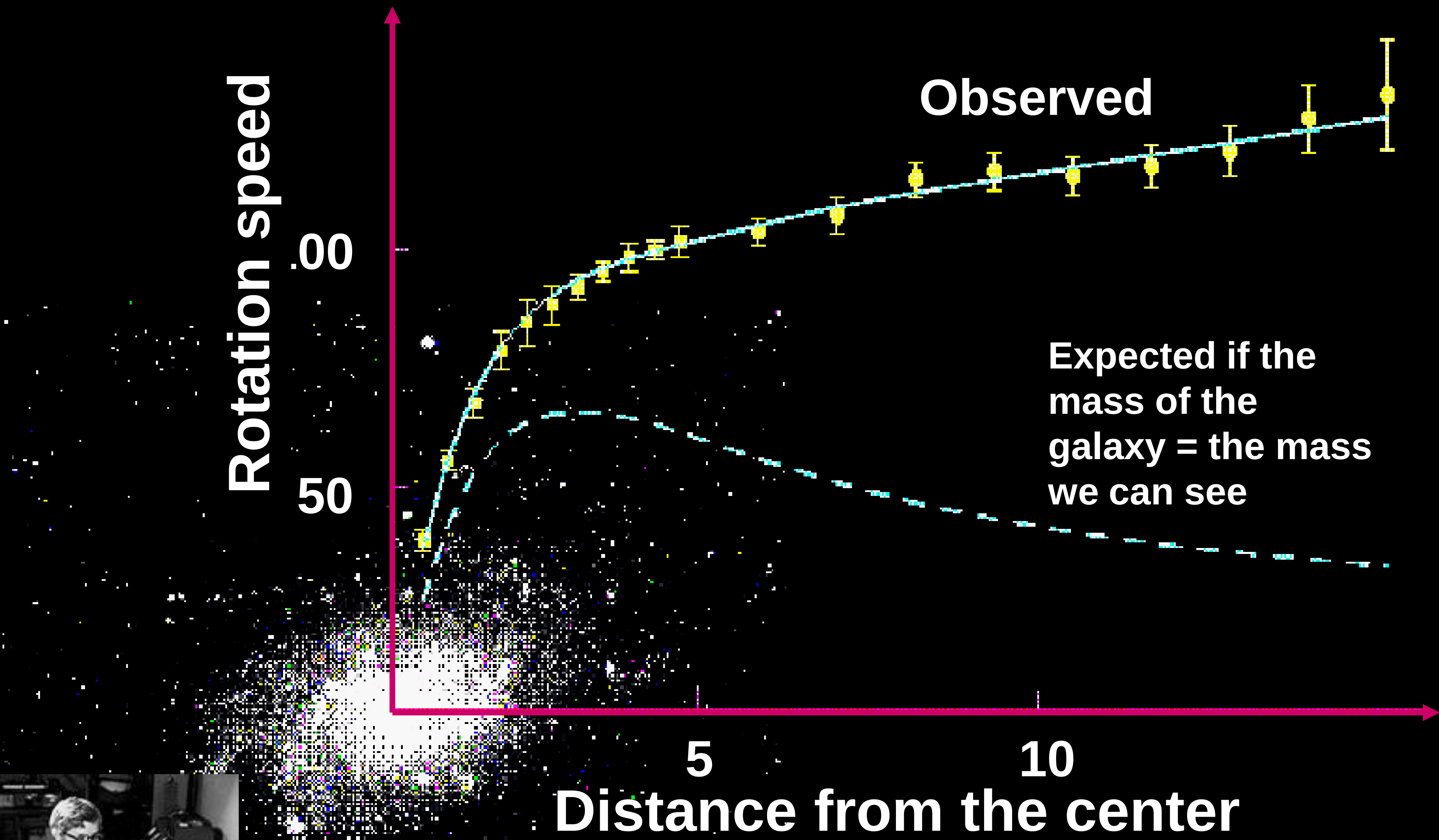
$$\frac{v^2}{R} = \frac{G\,M_{Sun}}{R^2}$$

measure v & R ⇨ M_{Sun}



$$\frac{v^2}{R} = \frac{G\,M_{GALAXY}}{R^2}$$

measure v & R ⇨ M_{Galaxy}

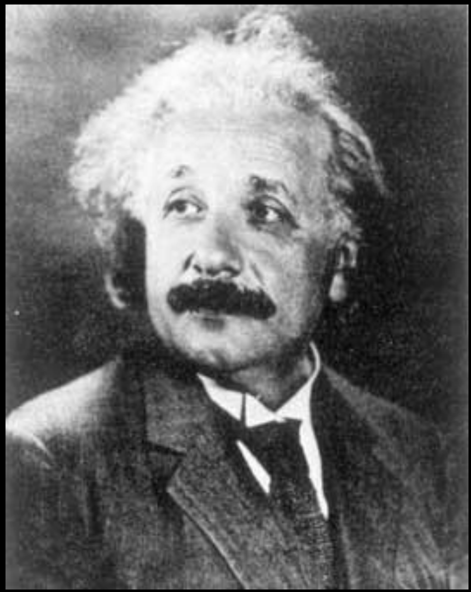


Vera Rubin 1980s

Some sort of invisible Mass must extend out ~10 times further than the stars!

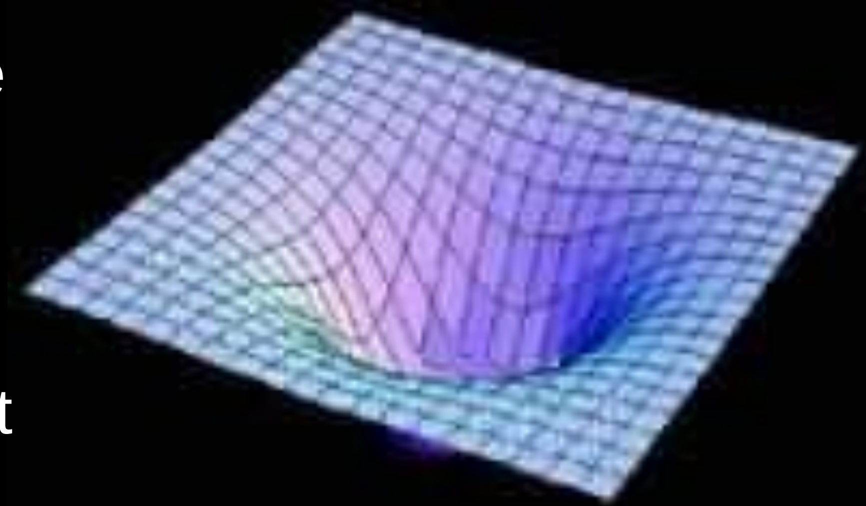
Evidence for Dark Matter from Lensing

Einstein: Gravity bends light



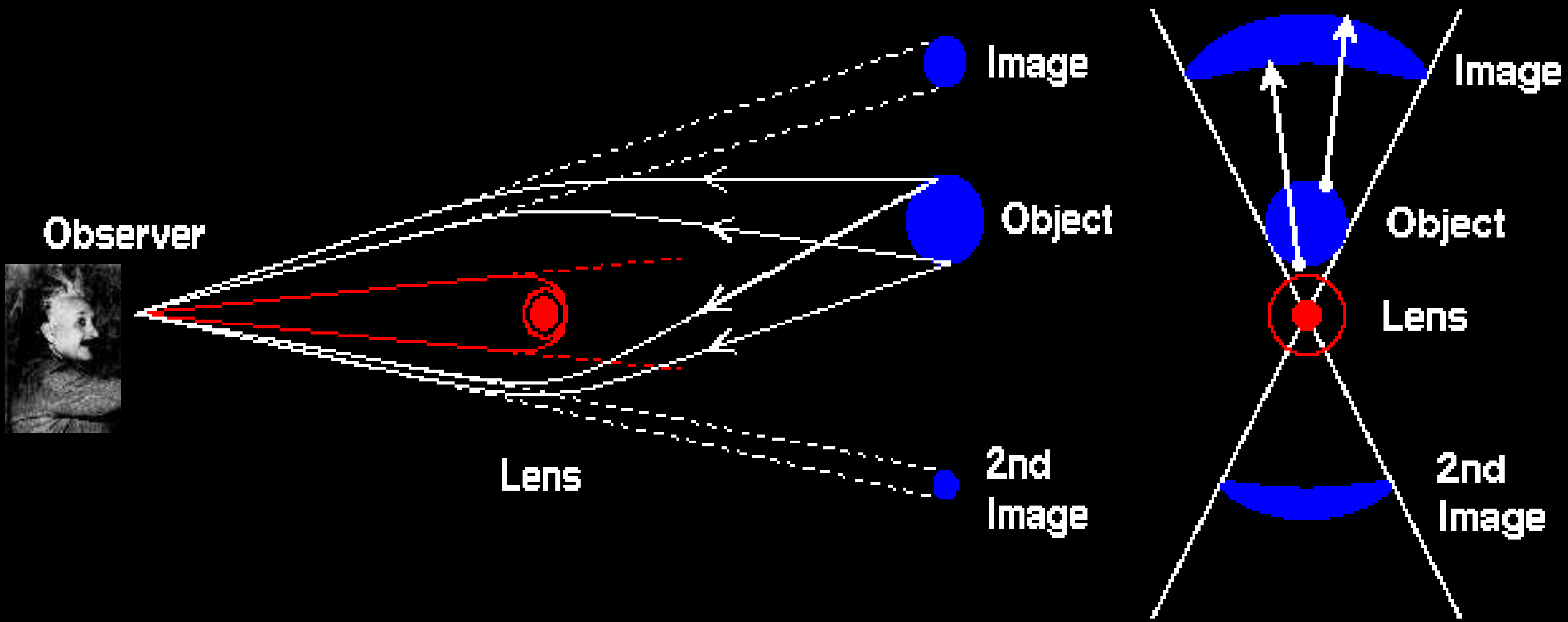
Light travels along straight lines unless it passes a massive object.

Light coming from behind a massive object such as a star, a galaxy, a cluster of galaxies or a clump of dark matter will be bent the same way a glass lens works.



The more massive the object, the more gravity it has and the more the light is bent

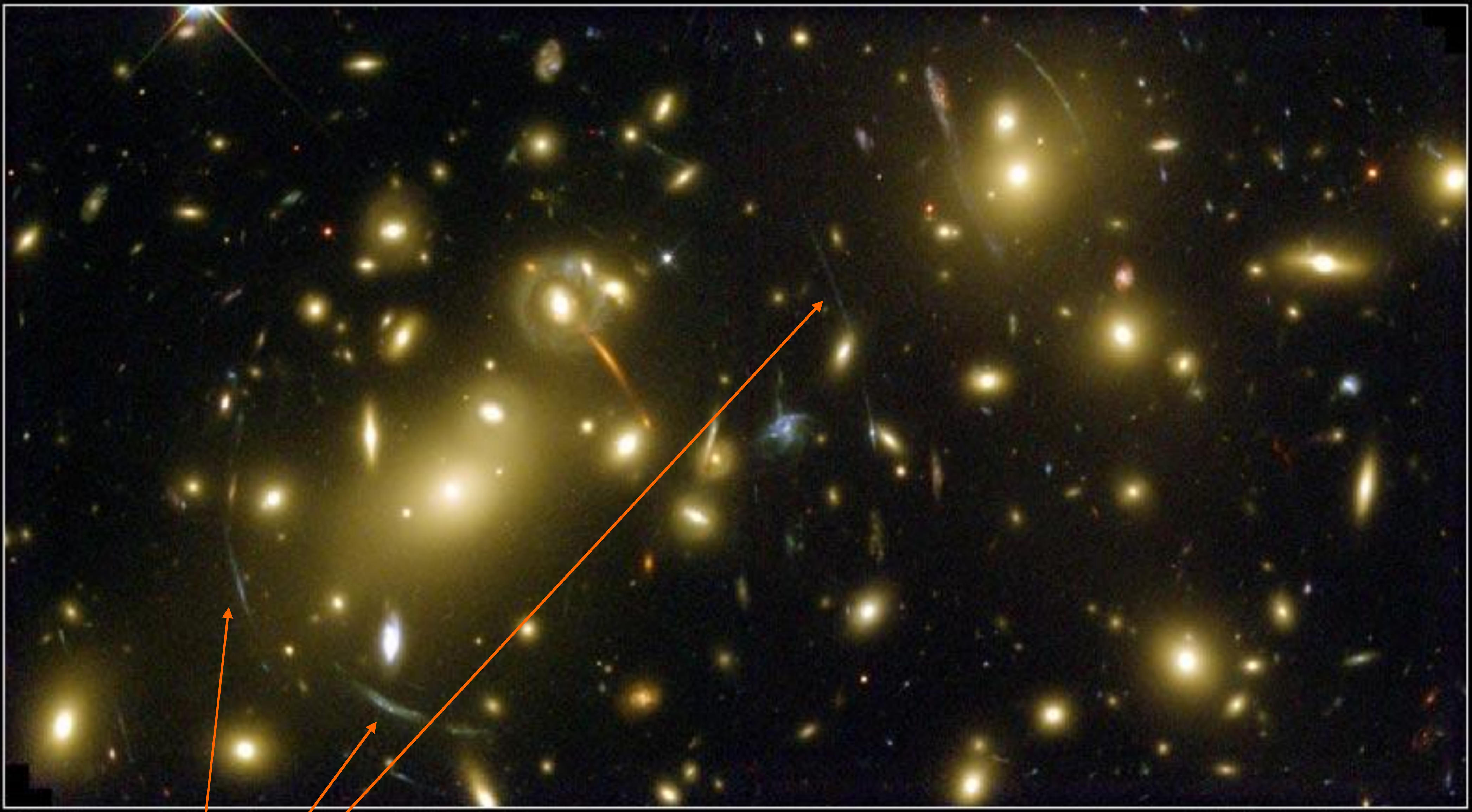
Gravitational Lensing Geometry



Gravitational Lensing: multiple images or pronounced distortion of images

Great book: *Einstein's Telescope: the hunt for Dark Matter and Dark Energy in the Universe* by Evalyn Gates (U. Chicago)

Zoom in on a galaxy cluster – Gravity from the invisible matter is bending light and we can see the distorted images that result



Galaxy Cluster Abell 2218 **HST** • WFPC2

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

giant arcs are galaxies behind the cluster, gravitationally lensed

The Milky Way Galaxy as we see it

The Milky Way Galaxy as it actually is!

What is Dark Energy?

We don’t know

It is causing the expansion of the universe to accelerate

Like dark matter, it doesn’t emit light (we can’t see it)

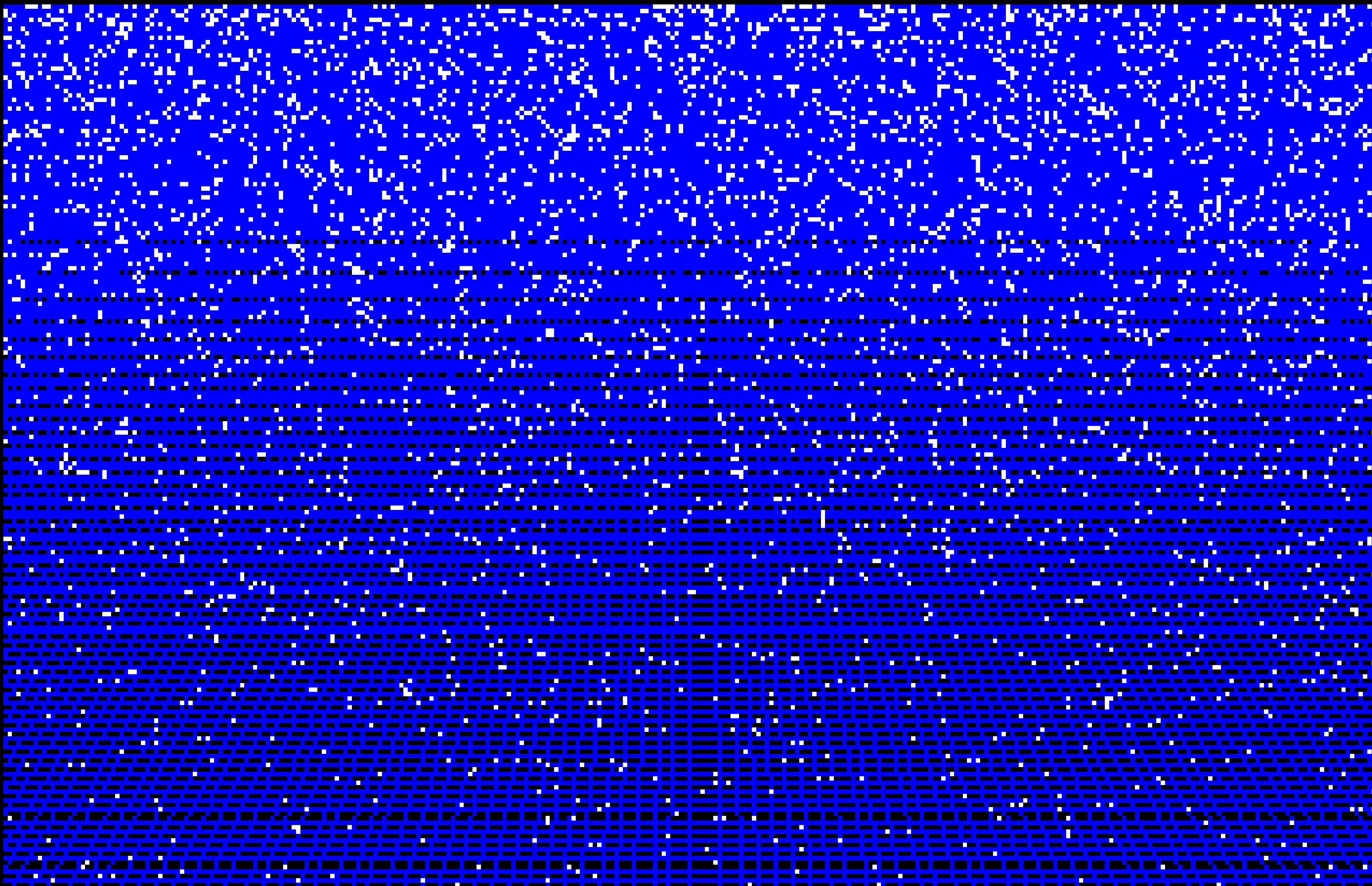
It contains about 3 times as much energy as Dark matter

Two leading ideas:

Dark Energy is a new form of energy with “negative pressure” (~anti gravity)

or a breakdown in our understanding of Gravity at large distances

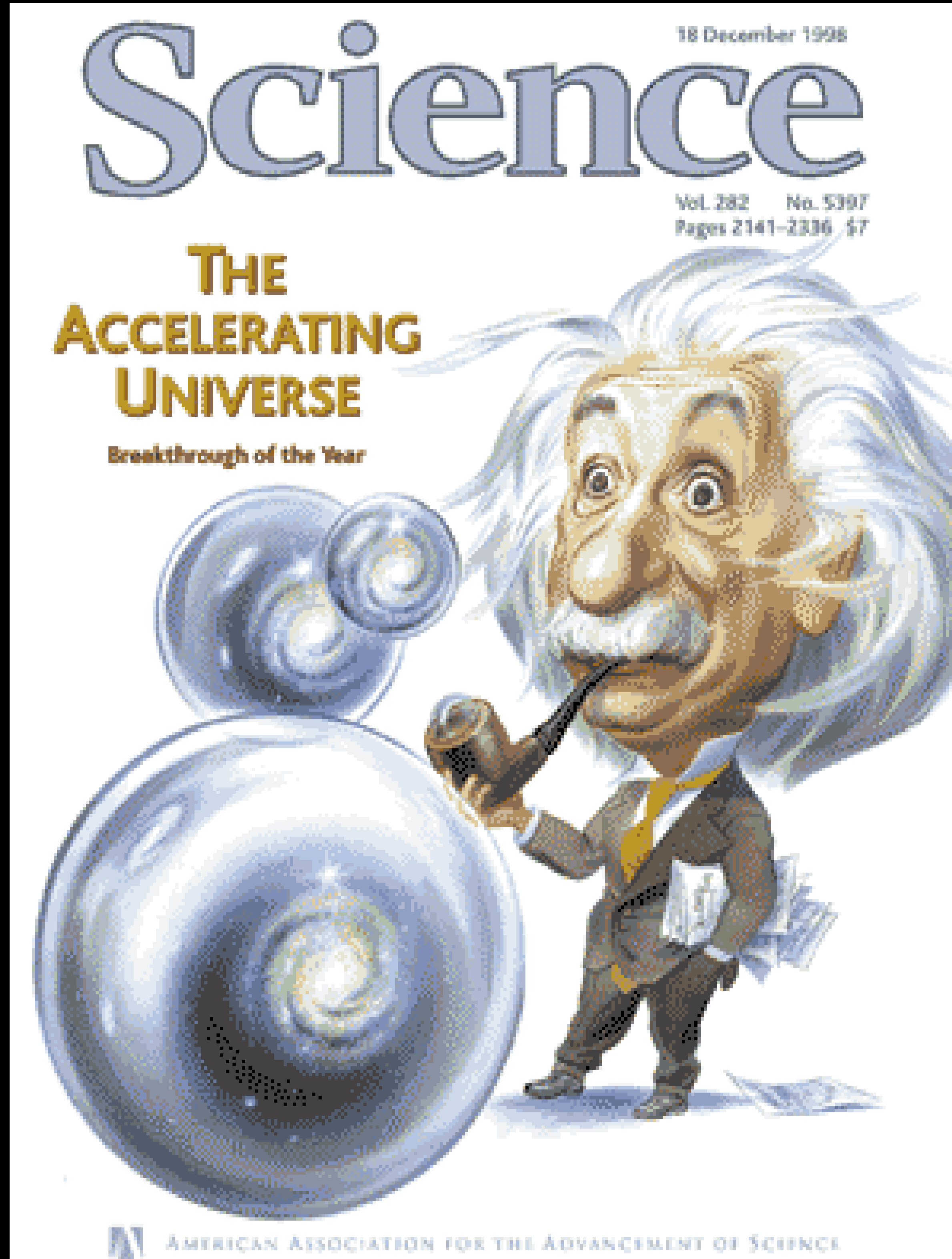
The expanding Universe:



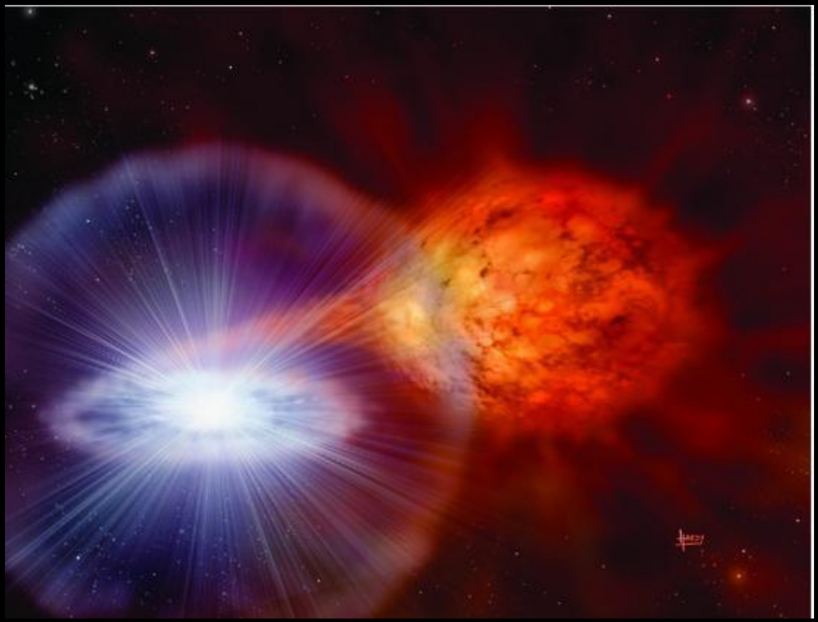
Big surprise of the 1990's

Two independent groups of astrophysicists measured the expansion rate of the universe using supernovae.

Both groups found that the expansion was accelerating!
This was the science Breakthrough of the year in 1998



Type Ia Supernovae are a type of Standard Candle



These happen when a White dwarf star, absorbs a companion star, and explodes.

These explosions are billions of times brighter than our sun.

The peak brightness of these type of explosions is standard and thus can be related to its distance. We use the measurements of distance to measure the expansion rate of the universe

There is about 1 Supernova every 50 years in the Milky Way

The explosions are usually visible for about 40 days.

The Sloan Digital Sky Survey (SDSS) is a telescope Fermilab helped build and operate.

It has a 2.4m mirror and no Dome

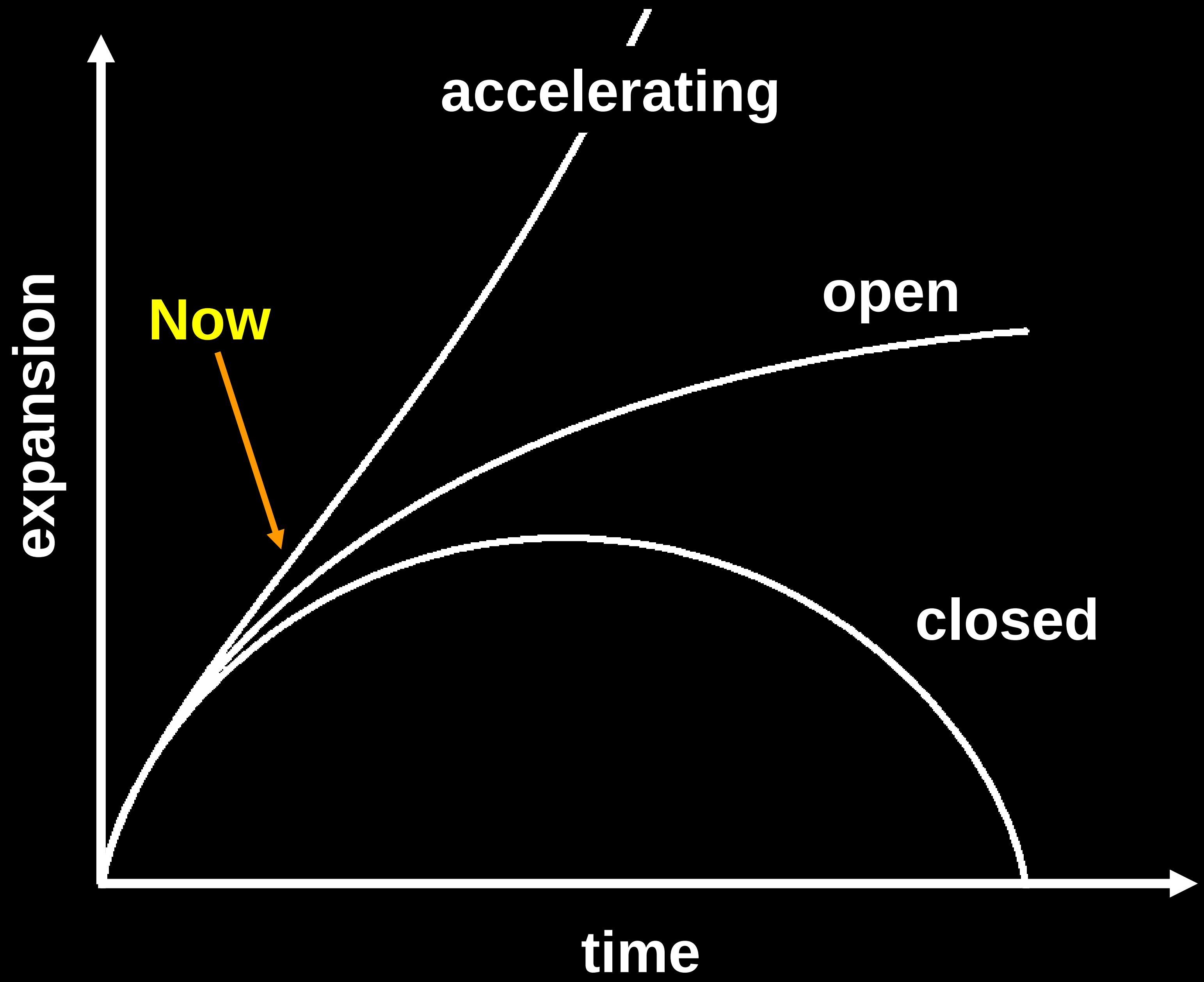
Located in New Mexico

- First started collecting images in 2000
- 120 MegaPixel digital camera

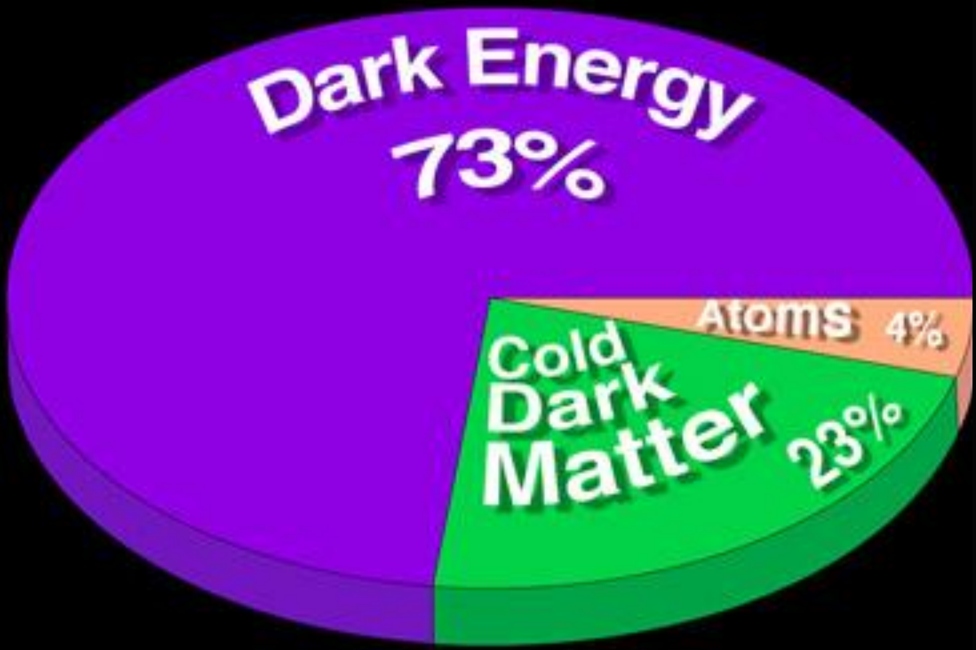
SDSS

has measured ~ 1 million galaxies and over 500 type 1a Supernova and also found that the expansion of the universe is accelerating

Our Universe's Expansion is Accelerating!



Cosmic Pie



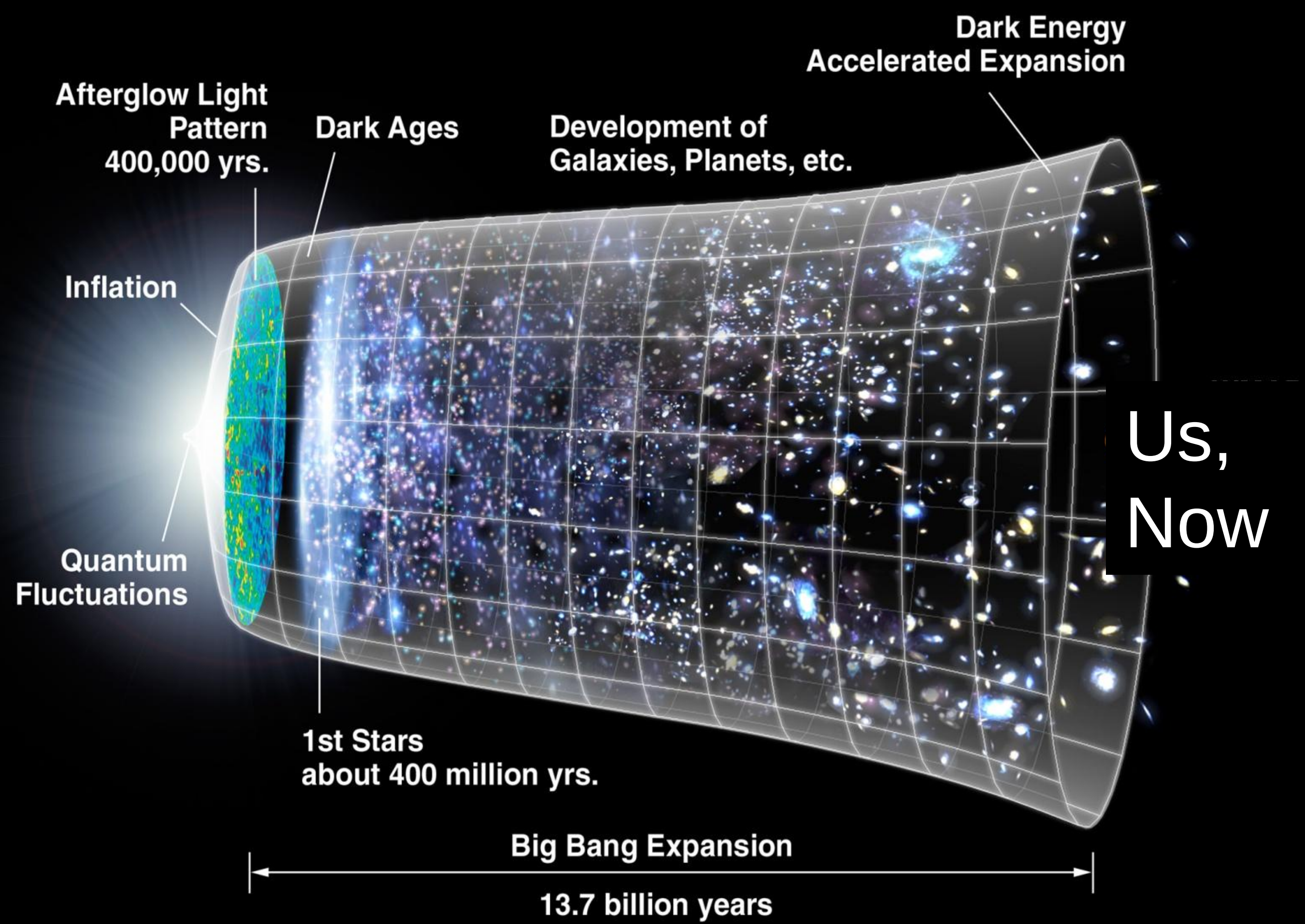
All the data point to a Universe that is now made up of 23% Dark Matter and 73% Dark Energy!

96% of the energy in the Universe is in stuff we did not know was there 30 years ago.

This was not expected.

2003 Science breakthrough of the year

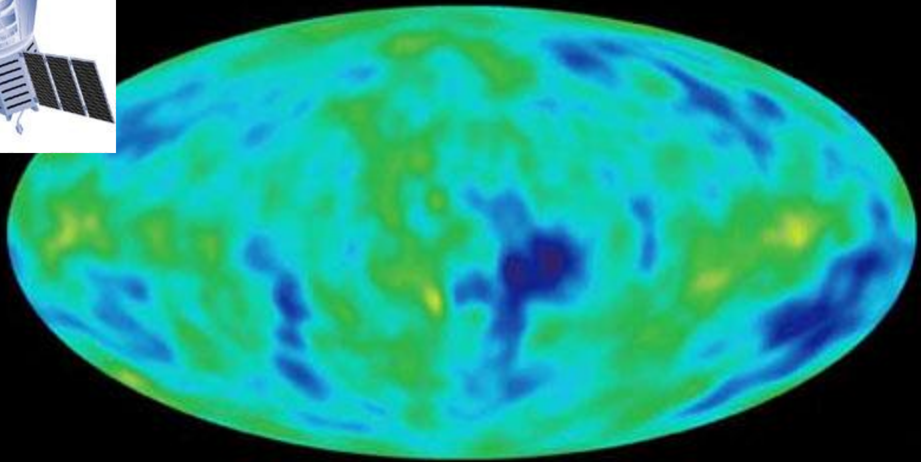
Cosmology as we understand it now



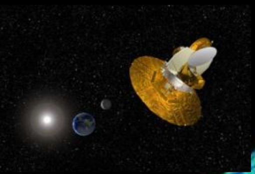
NASA/WMAP Science Team

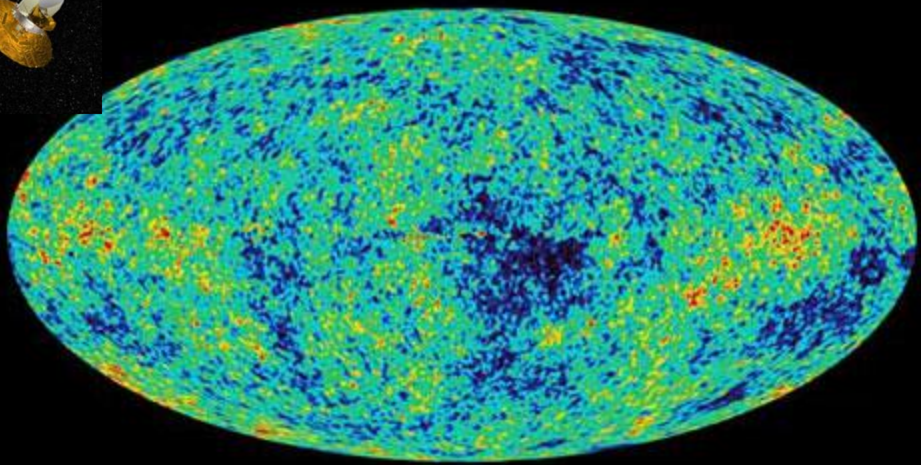
A picture of the **young** universe (~400,000 yrs old)

COBE and WMAP satellites measured the temperature (CMB) of the universe in all directions. This is the farthest back we can see. Before that the photons could not escape.



Launched in 1990 COBE





Launched by NASA in 2001 WMAP

Temperature of the Universe is the same is all directions:

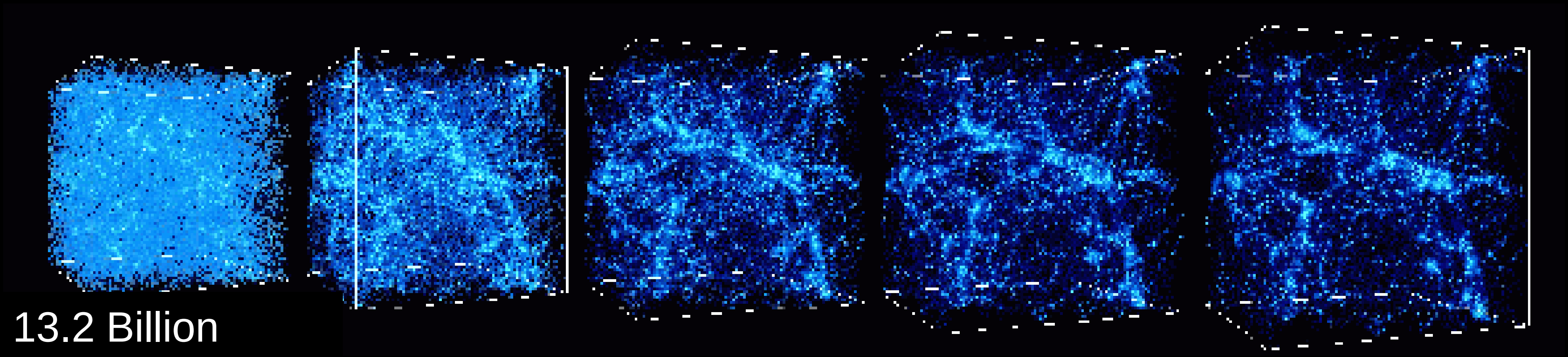
Red: 2.7+0.00001 deg Kelvin

Blue: 2.7-0.00001 deg Kelvin

1 Kelvin = -458 deg. Fahrenheit

The small differences in temperature evolve into the structures (for example stars and galaxies) we see today

Simulation of the evolution of Universe



13.2 Billion years ago "the dark ages"

Now

Each point is a simulated dark matter particle.

Add in gravity and dark energy and 13.2 billion years later we see clumps of dark matter that match the distribution of stars, galaxies, clusters of galaxies we see today

The number and locations of the clumps is determined by the initial temperature, gravity, the amount of mass, and by the expansion rate of the universe.

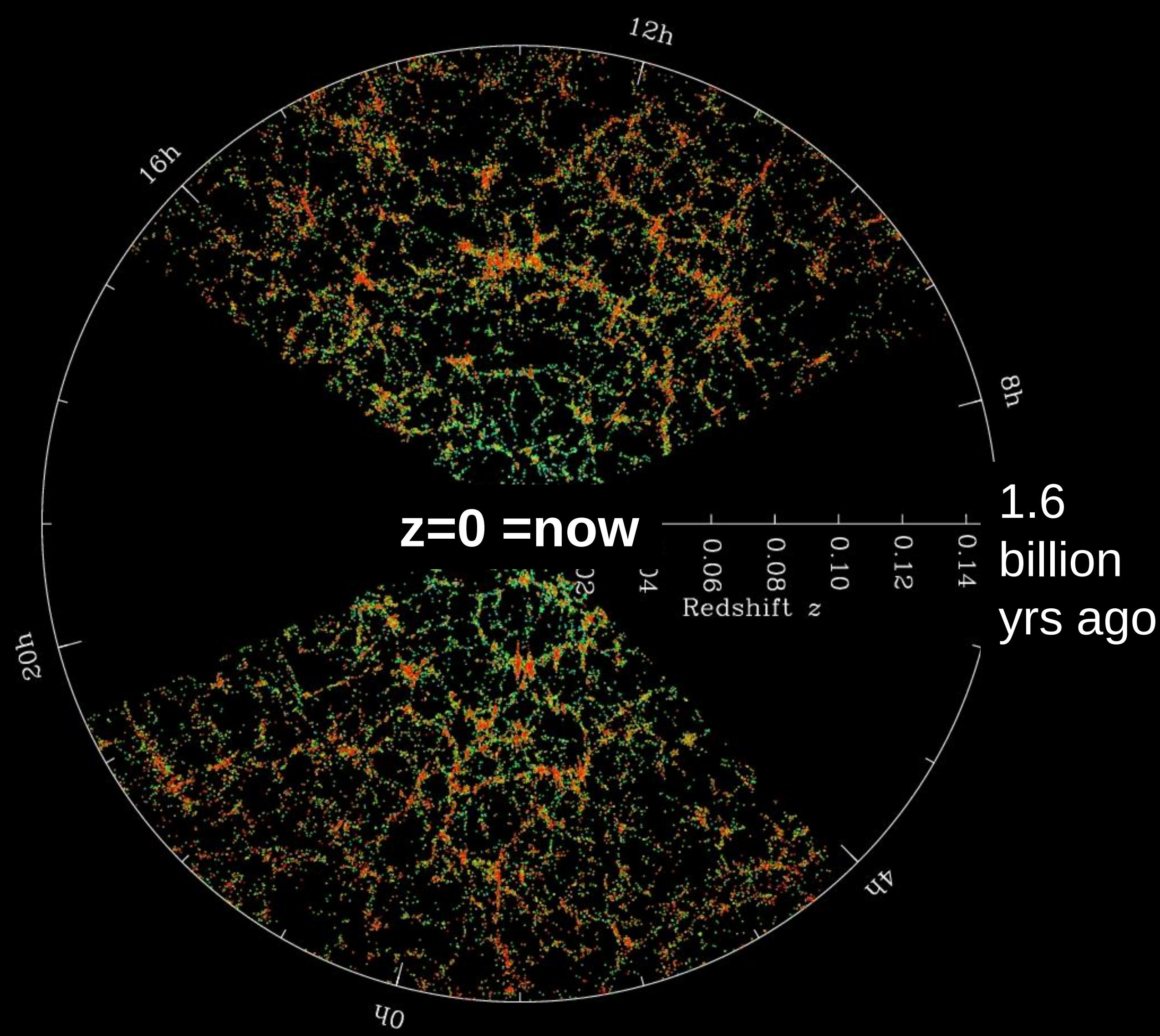
Picture of the RECENT universe

Sloan Digital Sky Survey (SDSS) has measured ~1 million galaxies

Each galaxy is represented by a point in the figure

Overdense regions are clusters of galaxies

There are also areas with no galaxies (voids)



How are Fermilab scientists studying Dark Matter and Dark Energy?

Dark Matter – try to detect Dark Matter particles from the Milky Way

- CDMS (Cryogenic Dark Matter Search)
- COUPP (Chicagoland Observatory for Underground Particle Physics)
- DAMIC (DArk Matter in CCDs)

Also look for Dark Matter in accelerator experiments at Fermilab and the LHC.

Dark energy (and Dark Matter) – take pictures of the sky and count the number, size and location of galaxies and galaxy clusters

- SDSS (Sloan Digital Sky Survey)
- DES (Dark Energy Survey)

Check out the Science Channel Series “Through the Worm Hole”

Episode “Beyond the Darkness”

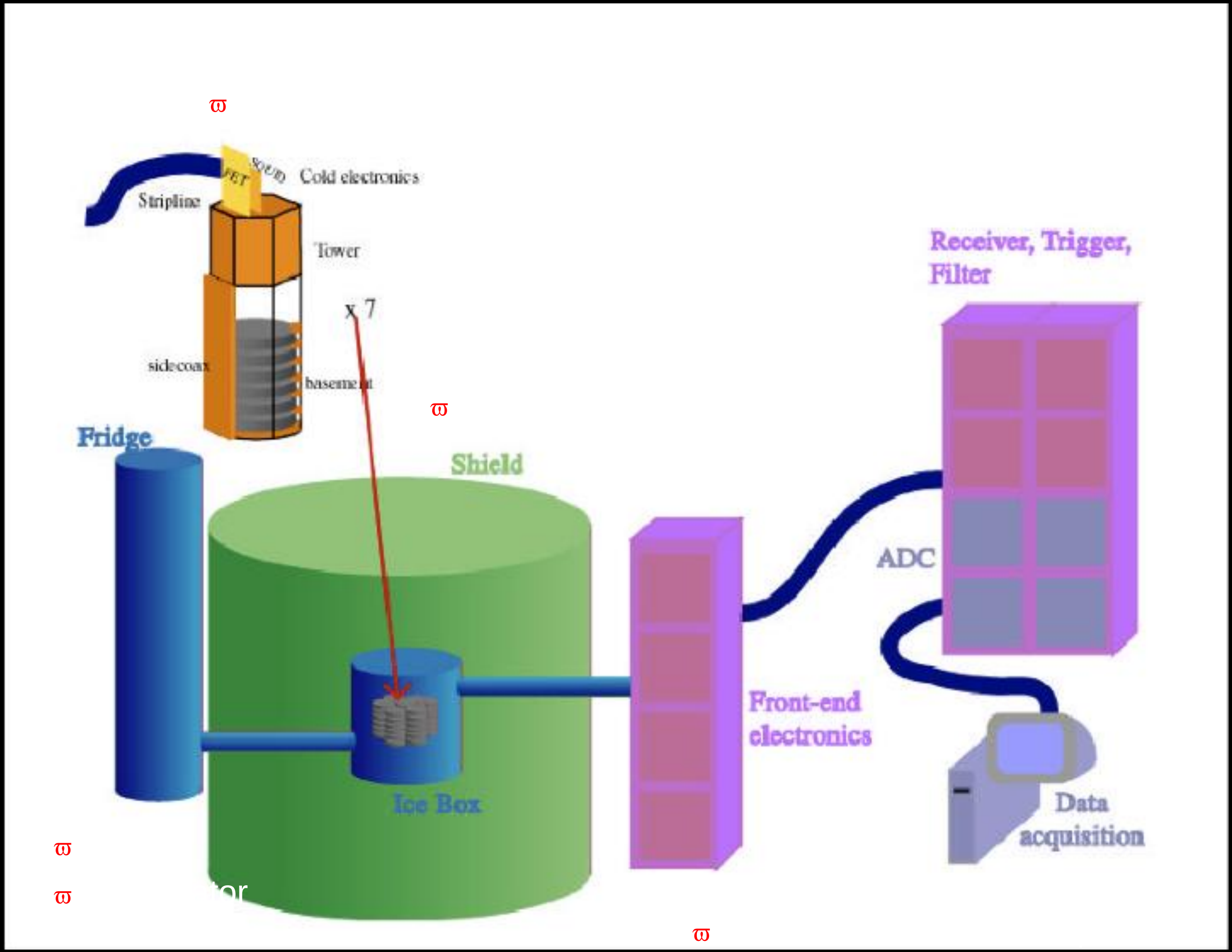
Filmed at Fermilab!

Dan Bauer talks about the dark matter search with CDMS and I talk about the Dark Energy Survey

Looking for Dark Matter Particles

CDMS (Cryogenic Dark Matter Search)

- Dark Matter Search
  - Detect Dark matter particles passing through earth
- Cryogenic
  - Cool very pure Ge and Si crystals to near absolute zero in order to measure single particle interactions.
- Shielding
  - Prevent particles of normal matter from reaching detectors

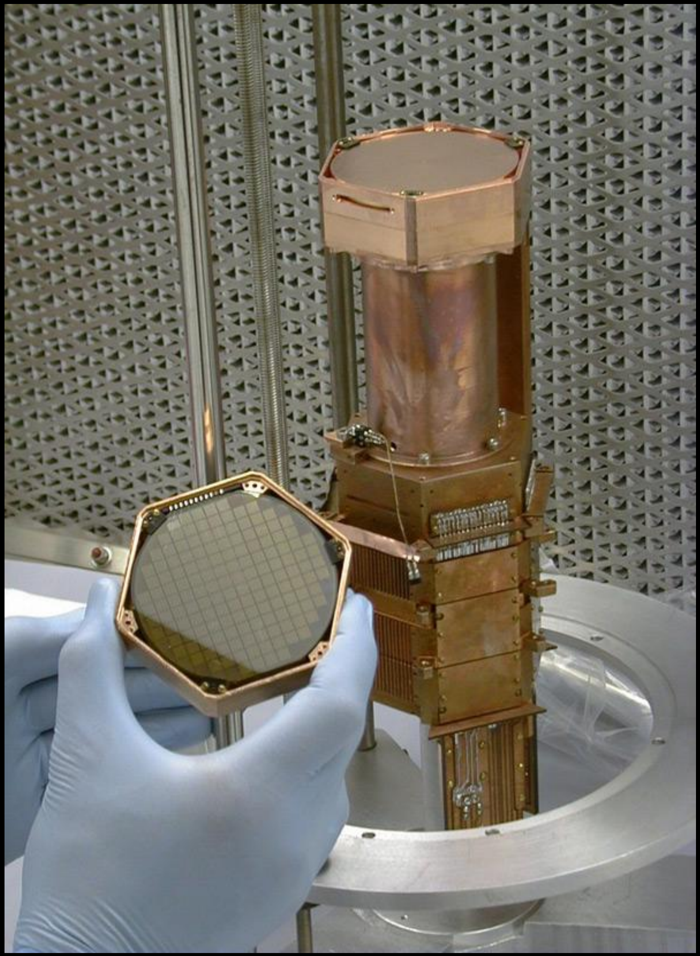


Looking for Dark Matter Particles with CDMS

Located a half-mile underground at the Soudan mine in northern Minnesota

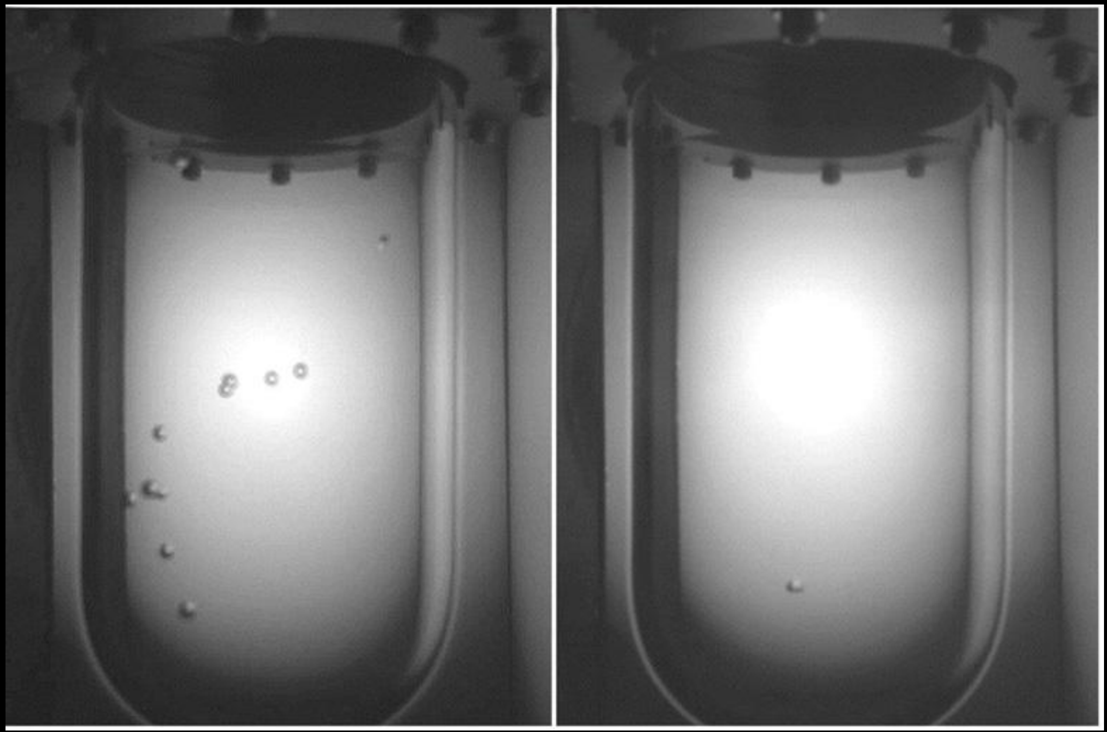
CDMS contains five towers of detectors.

When a dark matter particle hits the nucleus of the crystal particles inside the detectors, the nucleus recoils and vibrates the whole crystal.



Searching for Dark Matter Particles

COUPP – Chicagoland Observatory for Underground Particle Physics



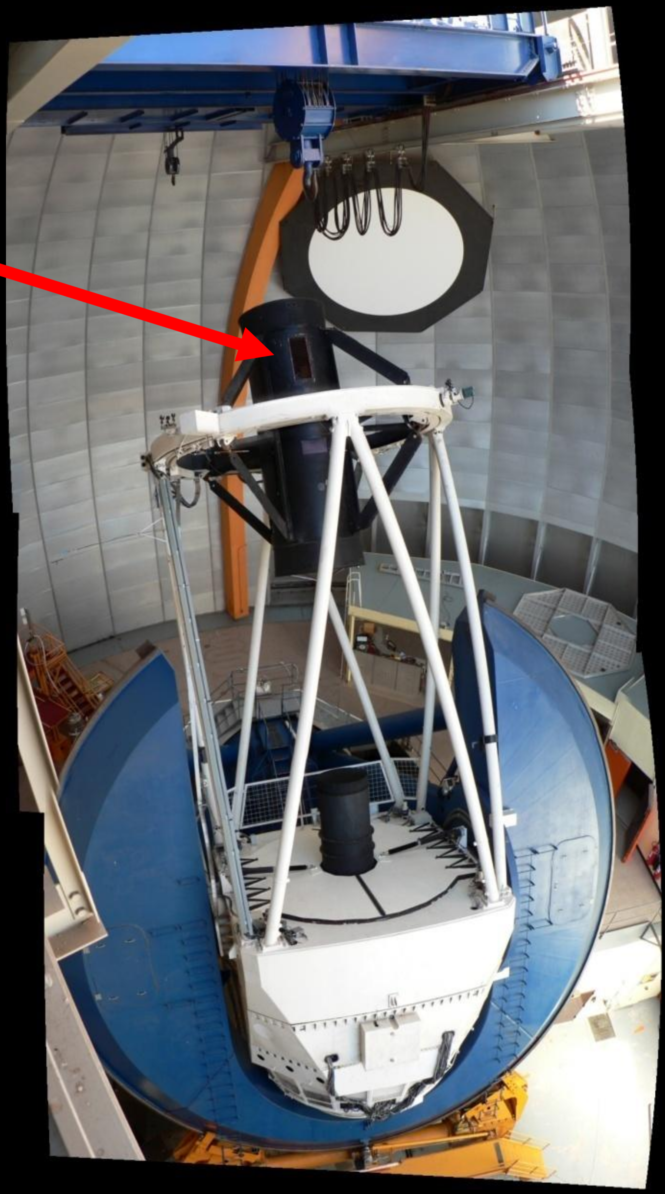
When a charged particle zips through the liquid, it triggers boiling along its path, which is visible as a series of small bubbles. Dark matter particles leave a single bubble in contrast to the multi-bubble tracks left by other particles.

Looking for Dark Energy : The Dark Energy Survey (DES)

Use an existing telescope and replace the existing camera with a new 520 Mega pixel digital camera

Use the new camera to take images of ~ 12% of the southern sky and look for Dark Energy.

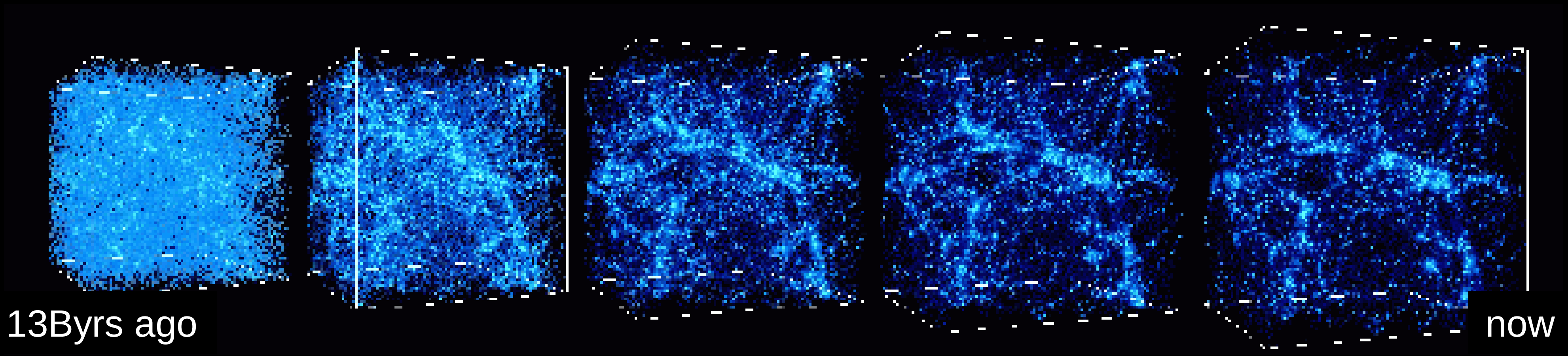
The telescope and new camera will be used by the US astronomy community when DES is not observing.



Blanco
4m Telescope
at the Cerro-Tololo
Inter-American
Observatory (CTIO)
Operated by NSF

Cerro Tololo Inter-American Observatory:
Public telescopes operated by the National Science Foundation (NSF)

Multiple ways to measure the effects of Dark Energy



The Dark Energy Survey will measure the effects of Dark Energy and Dark Matter 4 different ways and by combining the results we hope to get a better understanding of what they are

Gravity and Expansion

1) Count the Galaxy Clusters as a function of time

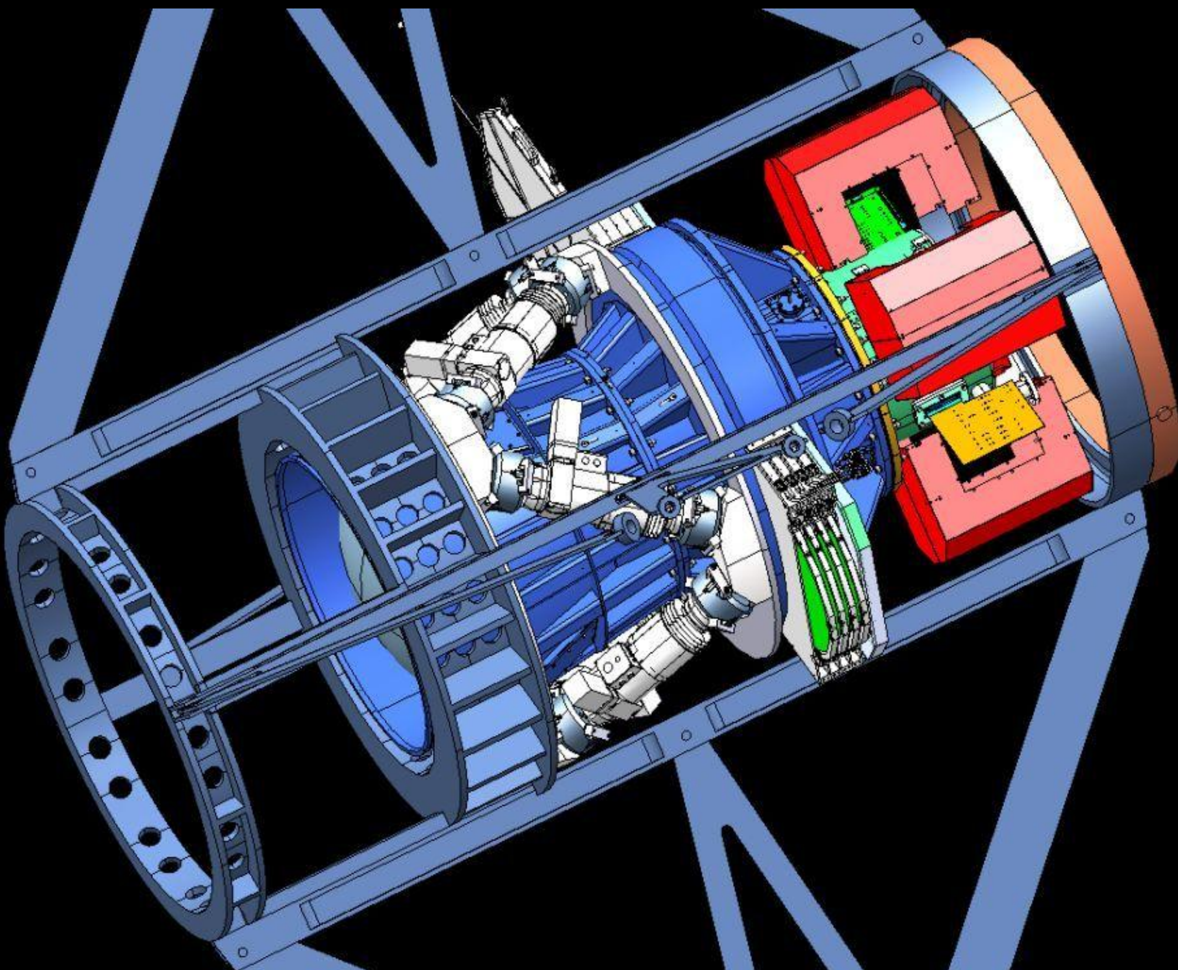
2) Measure the distortion due to galaxy clusters and clumps of dark matter (Lensing)

Expansion

3) Measure the space between galaxies as a function of time

4) Use Supernovae to measure the expansion rate

The DES Instrument: DECam – a really big Digital camera



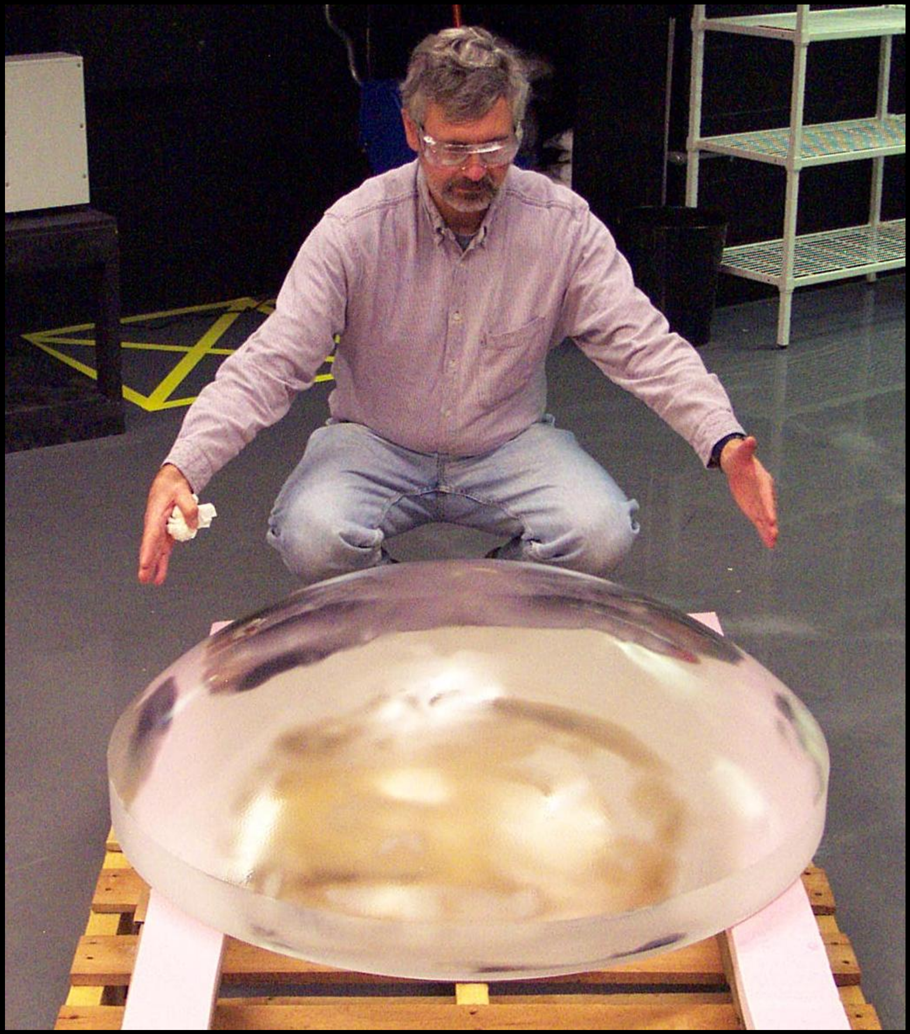
520 MPix digital camera

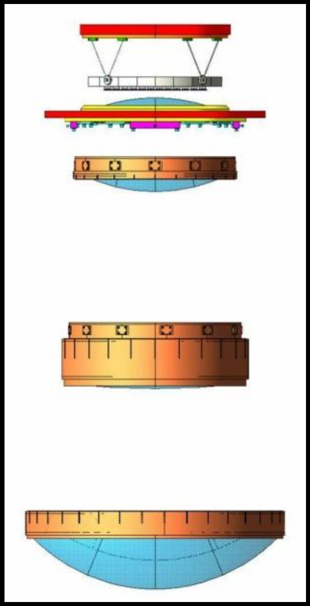
The “film” of the digital cameras you can buy off the shelf are called CCDs. DECam has similar CCDs, but more of them and they are more sensitive to light.

Lenses are about 1m diameter

Total weight is more than 3 tons

Lenses made in the US and in Europe





Design: 5 lenses

Largest is~ 1m diameter

Smallest is ~ 0.5m

Polishing started in May 2008

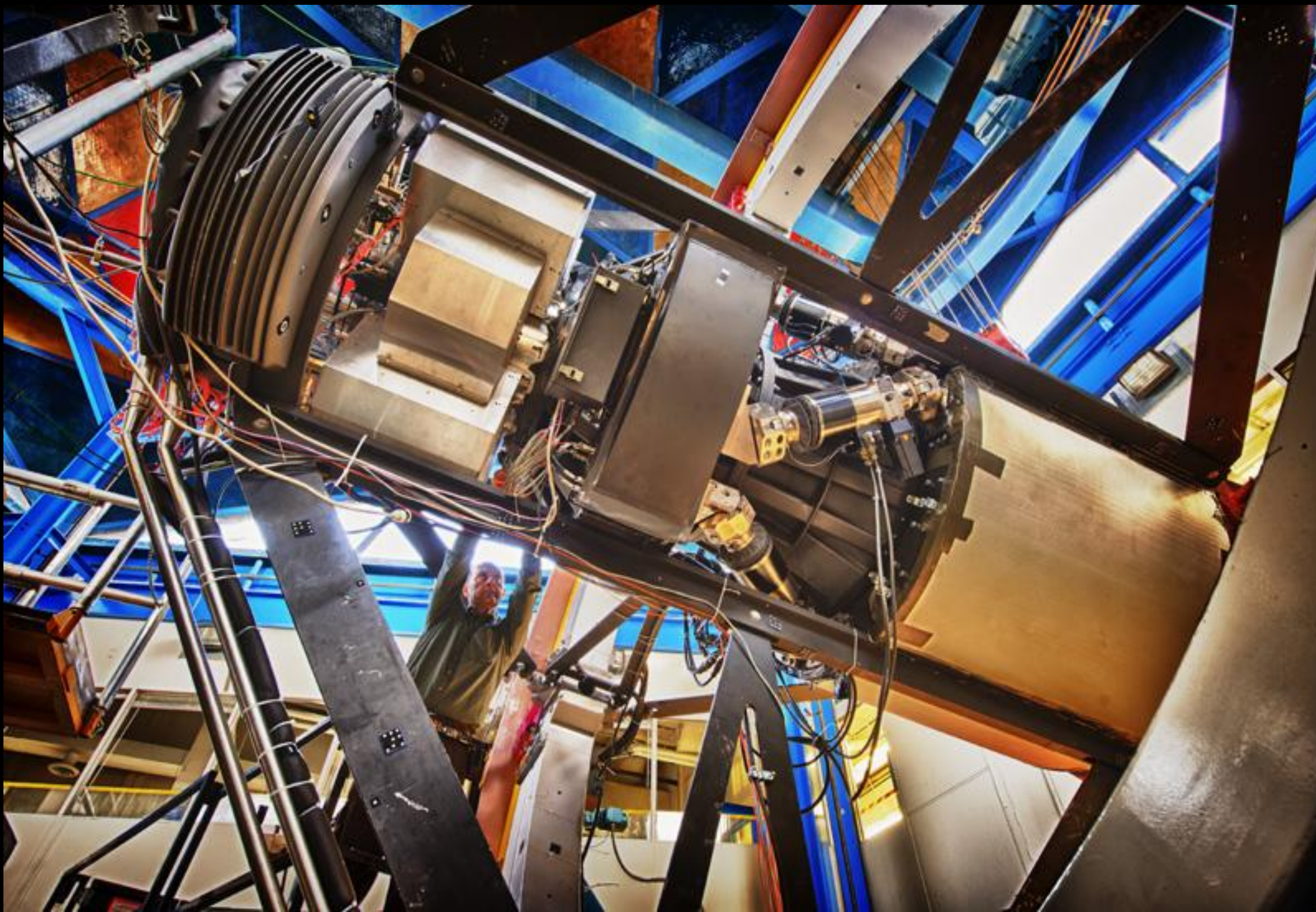
Finished May 2011

Cost of all 5 lenses ~ $3M

Blank inspection at Corning glass in upstate New York

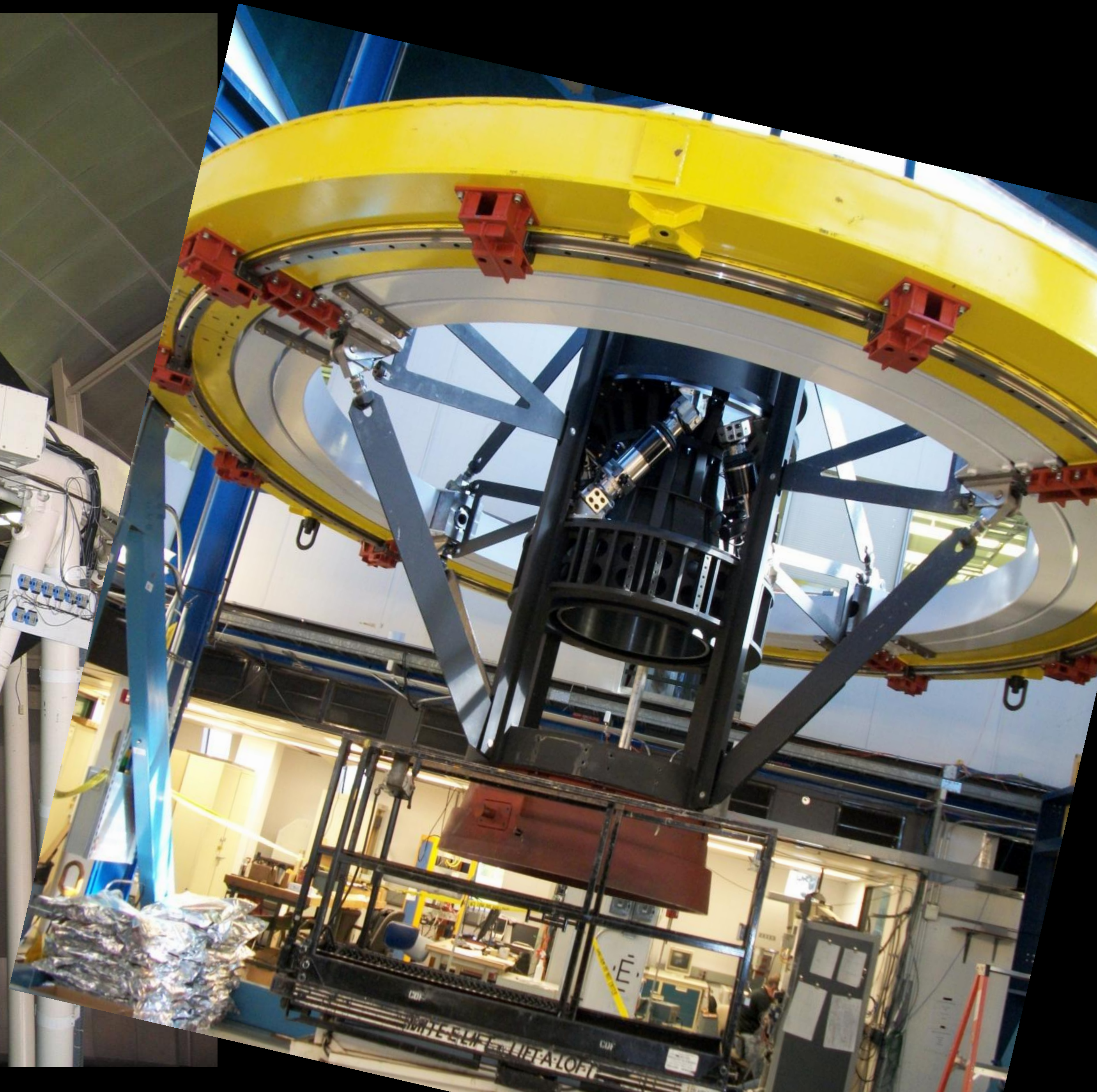
Polishing Complete!

At Fermilab we built a copy of the top end of the Telescope
We put everything (except the lenses) together and tested it in all orientations before shipping to Chile.

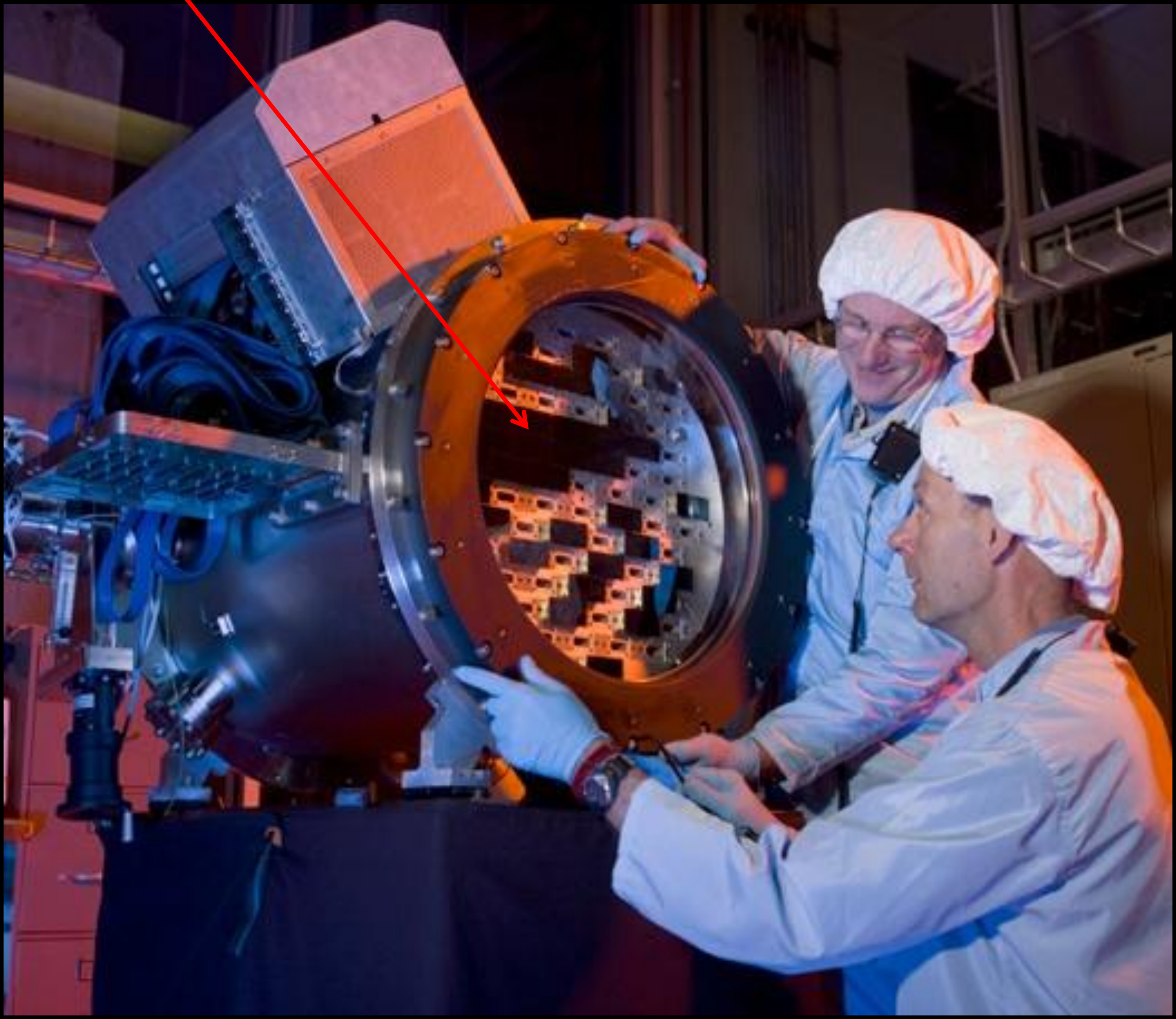


The Blanco Telescope

Fermilab



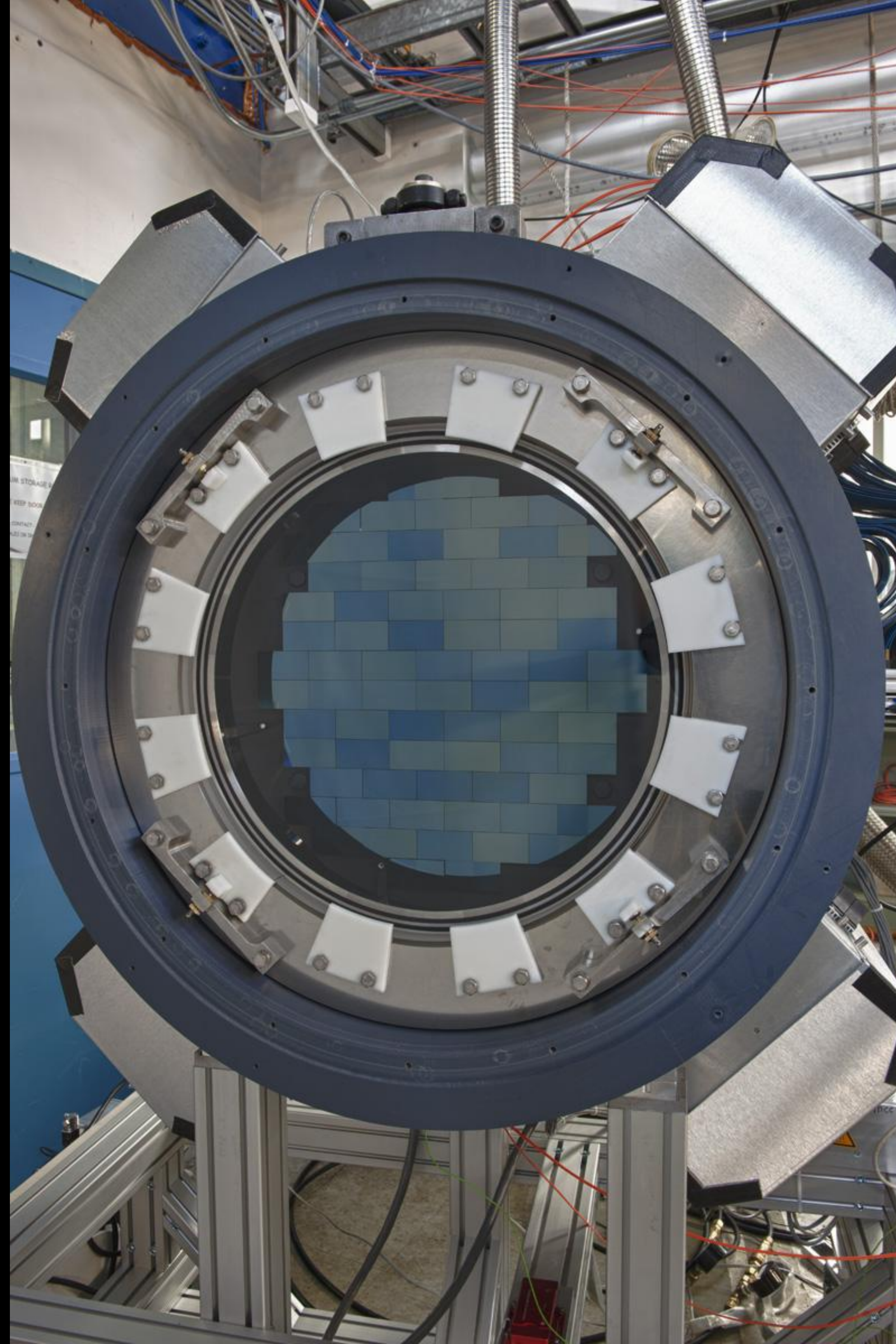
Full size prototype used for testing at SiDet
The CCDs are the “film” in the camera



DECam Imager at Fermilab with all the CCDs installed.

It sits on a cart so we can move it around.

Will ship to Chile in a couple weeks!



The Blanco is in the foothills of the Andes Mts. Only about 7500 ft high

Normally a desert, but this year they have had lots of snow!

Five of us from Fermilab

arrived in Chile July 7th for installation of the DECam Liquid Nitrogen cooling system.

I just got back!

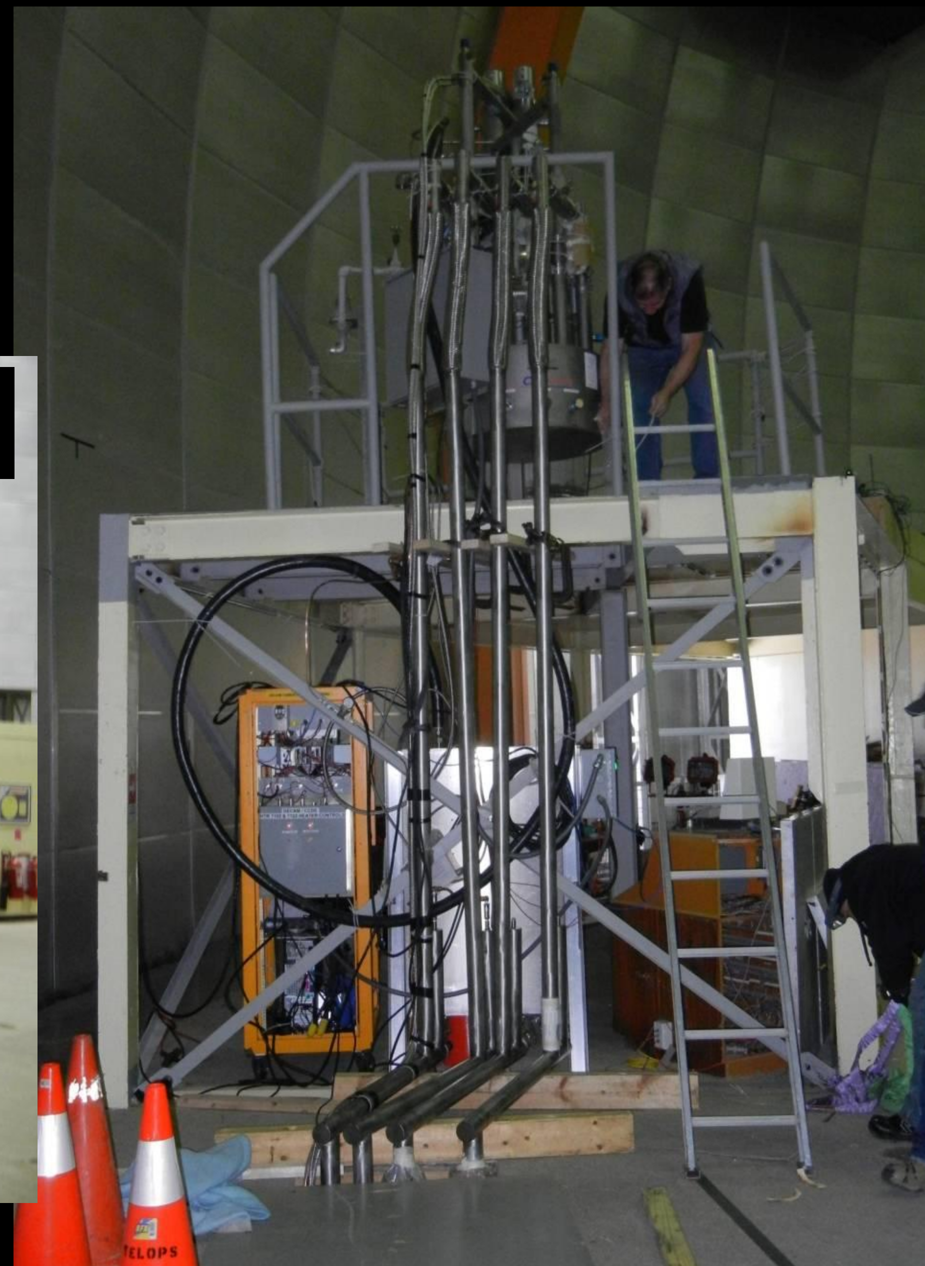
July 17th

9 inches of snow, we were stuck on the Mt until they could clear the road

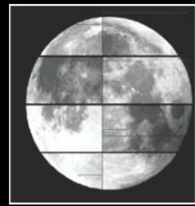
Inside the Blanco Dome


July 7th

July 20, 2011

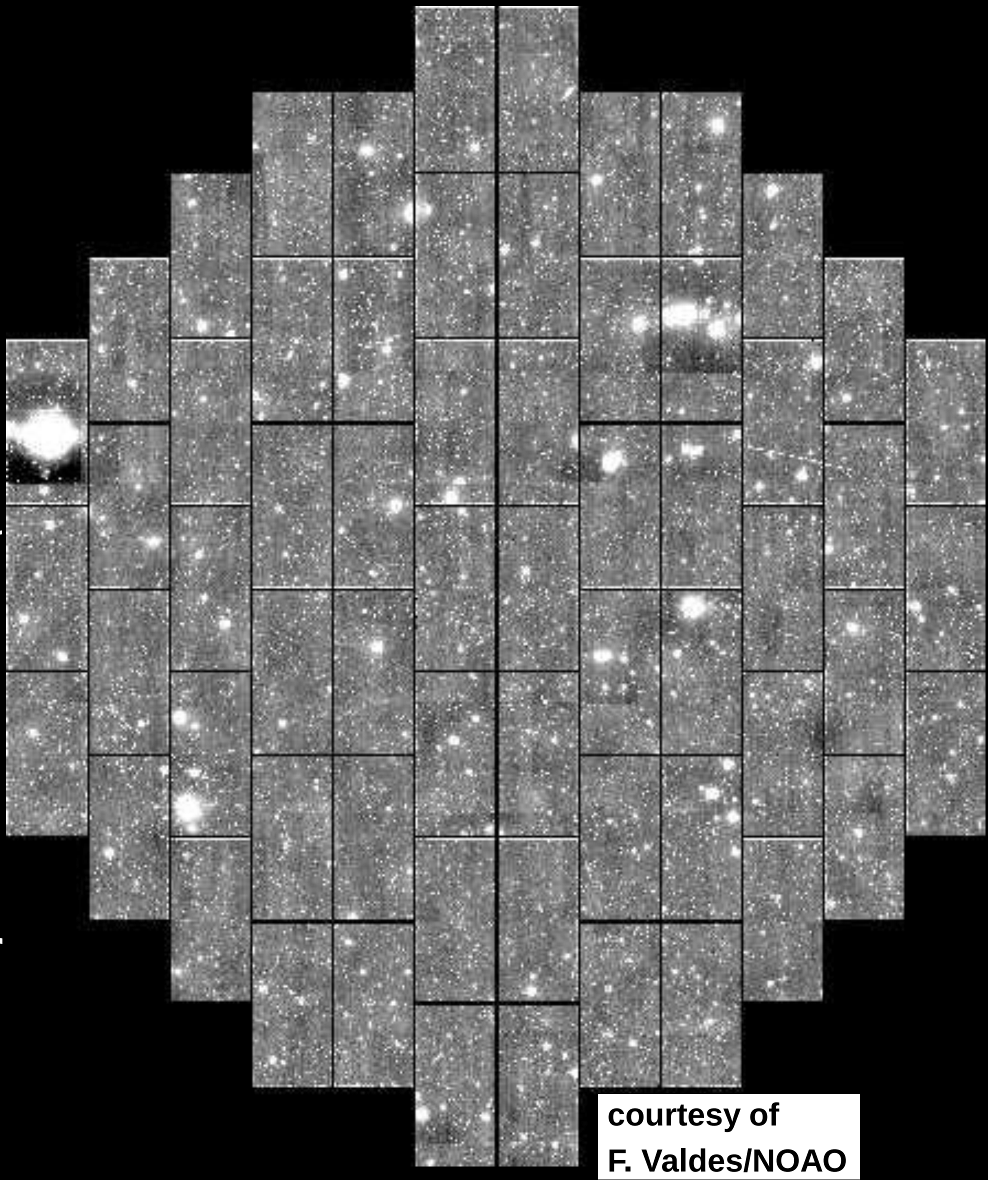


DECam Simulated Image



Each image

- 3 sq. deg.
- ~ 20 Galaxy clusters
- ~ 200,000 Galaxies
- 520 Mega pixels (62 CCDs)



Each night ~ 300 GB of image data

We will use 500 nights for the Dark Energy Survey

The large field of view lets us cover the sky in a reasonable amount of time.

Why are we studying Cosmology at Fermilab?

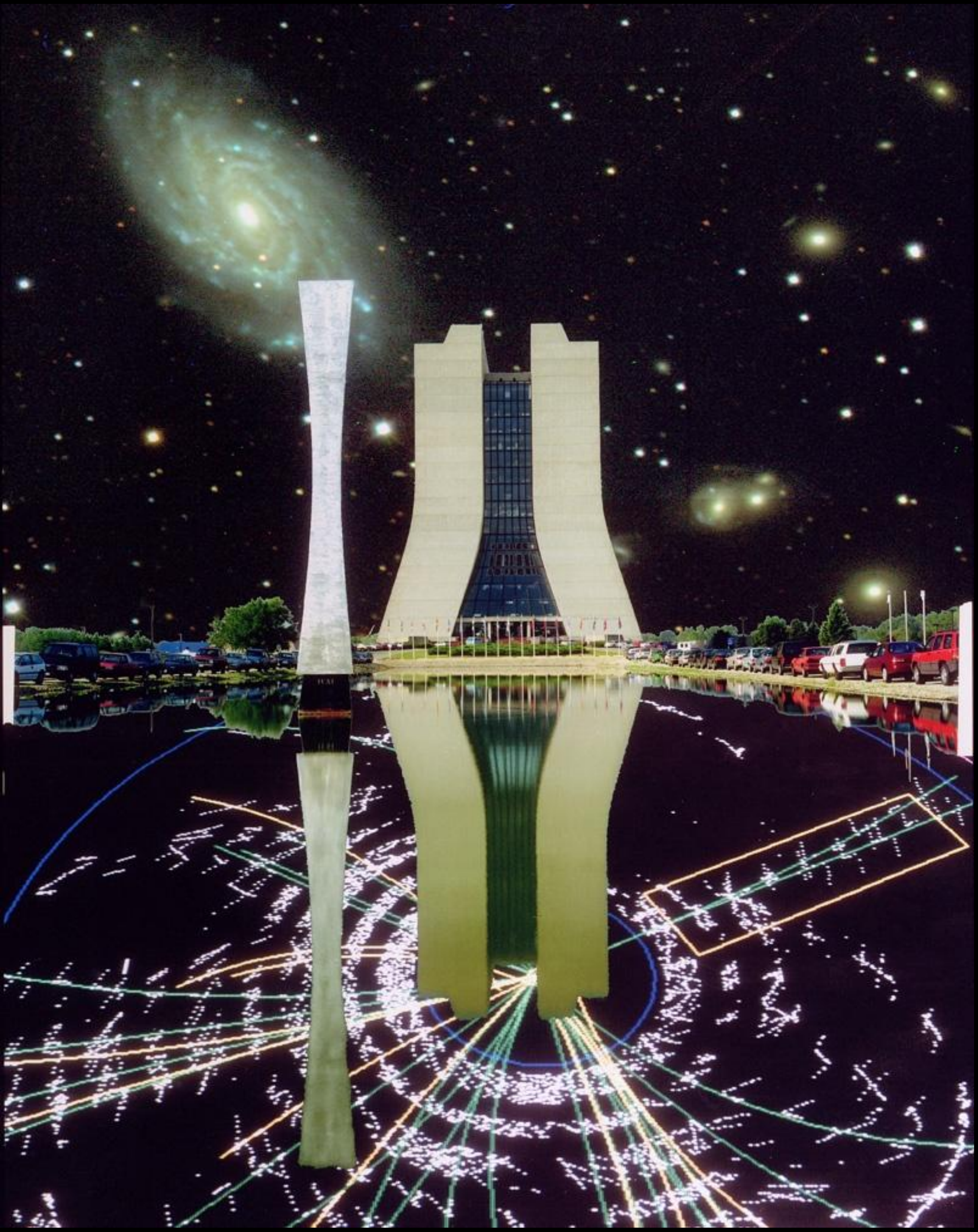
- To understand the origins of the universe and the fundamental forces of nature

- To understand the nature of the mysterious dark matter. Is it a new type of elementary particle?

- To determine properties of dark energy which is responsible for acceleration of the expansion of the universe

- To test Einstein’s theory of gravity in new ways

Conclusions



Dark Energy and Dark Matter make up 96% of the energy in the Universe and yet their properties are mysterious

The Cosmic Frontier projects at Fermilab are going to make new measurements to help unravel these secrets


QUESTIONS?